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A RAND NOTE

Methodological Considerations in Using Simulation to Assess the Combat Value of Intelligence and Electronic Warfare

Steven C. Bankes

RAND

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Steven C. Bankes

Prepared for the United States Army

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PREFACE

This Note describes issues that must be addressed if the contribution of intelligence and electronic warfare/target acquisition (IEW/TA) systems to combat outcomes is to be reliably assessed through the use of simulation models. The analysis reported here was done in the context of the project "Measuring the Operational Value of Intelligence, Electronic Warfare and Target Acquisition (OPVIEW)," which was undertaken by the Arroyo Center for the Army under RAND's Applied Technology Program. Its objective is to develop a methodological approach and supporting model as tools for analyzing and measuring the operational value of IEW/TA in combat outcome terms. This Note documents general considerations that motivated the approach being taken on the OPVIEW project. The design of the OPVIEW modeling environment and associated models will be described in subsequent documents.

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SUMMARY

The Operational Value of intelligence and electronic warfare (OPVIEW) project is endeavoring to develop means for evaluating intelligence and electronic warfare/target acquisition (IEW/TA) systems in terms of their contribution to combat outcomes through the use of simulation. The challenge of adequately representing the intelligence process in a simulation model is being met through model representations. These will be described in subsequent documents. A greater and more fundamental challenge is to contend with potentially large sensitivities of combat outcomes to multiple assumptions having unresolvable uncertainties.

Many details of future combat situations are quite uncertain, which poses a problem for the use of simulation in assessing combat outcomes. Furthermore, the inclusion of IEW/TA causes a substantial increase in the amount of uncertainty above what must be addressed in simulations directed primarily toward lethal systems. Consequently, the use of simulation in evaluating the contribution of IEW/TA to combat outcomes requires innovative approaches.

The problem of uncertainties in models is generally met through sensitivity analysis where possible errors in inputs to the model are estimated and corresponding error estimates on the outputs are calculated. Unfortunately, for most realistic simulation models of complex processes the number of runs per case required for a thorough sensitivity analysis is astronomical. If simulation models are to make a contribution to evaluating IEW/TA, the number of excursions required to bound output uncertainties must be kept tractable.

Aggressive sensitivity analysis can be pursued in several ways:

- Aggregated modeling limits both the number of uncertainties explicitly considered and the time for individual runs.
- Transparent modeling allows for rapid model revision, facilitating the use of multiple model variants for exploration of the effects of nonparametric assumptions.
- Question-driven model development provides focused modeling limiting irrelevant factors.

- Selectively varying the resolution of the models allows for structuring the search of the universe of cases and optimizing the utilization of analytic resources.
- Analytic strategies provide a "top-down" structuring of the list of cases that must be run.

For IEW/TA systems, a large portion of the value derived from situation assessment comes from both avoiding being surprised and exploiting special opportunities. Consequently, the incremental value of an IEW/TA system will manifest itself primarily in special cases where such surprises or opportunities exist. Where the added value of an IEW/TA system is being estimated through a series of simulated cases sampling plausible situations, such critical cases should be oversampled. A generic study might involve discovering "interesting" cases through an exploration of the space of plausible models and then studying the implications of different IEW/TA attributes on those cases. The process could well be iterative as new cases are identified in the course of analysis.

A specially designed computer environment could support this style of modeling IEW/TA's effect on combat outcomes in several ways, particularly through

- Programming languages and software tools supporting interactive and adaptive modeling.
- Aggregated and parameterized baseline models that may be modified in the context of specific studies.
- Transparent model computer code.

These facilities would permit running many cases in support of any specific analysis of combat value. Generating these runs may be regarded as the first half of an analysis of combat value. The second half is to generate a coherent picture of all the relevant tradeoffs, to boil down the complexities of the sensitivity analysis to a representation that will provide useful input to decisionmaking.

Such a simulation environment would be useful for asking not only "What is the value of an IEW/TA system" but also "When (under what conditions) will it have that value?" and "Why does it have value?" This tool could prove useful for examining

alternative mixes of systems, understanding synergistic effects (e.g. cueing), and seeing implications for employment issues. Consequently, while OPVIEW has focused on measuring the combat value of IEW/TA, the product should provide not just measurements but rather decision support for a broad range of issues. OPVIEW and other projects should endeavor to produce a decision aid that will illuminate both tradeoffs and essential uncertainties. Such a tool could be of value to decisionmakers who must consider costs and risks as well as benefits.

ACKNOWLEDGMENTS

The ideas articulated here have been developed in the context of vigorous research into simulation at RAND, and special thanks are due to colleagues Patrick Allen, Edison Cesar, Edward Hall, and all the members of the OPVIEW teams.

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I. CHALLENGES TO ASSESSING THE VALUE OF IEW/TA BY SIMULATING COMBAT

The relative value of systems for intelligence and electronic warfare/target acquisition (IEW/TA) may be determined in a variety of ways including the comparison of technical characteristics, ability to provide estimations of commanders' information need, or subjective judgment by experts. The OPVIEW project is endeavoring to develop means for evaluating IEW/TA systems in terms of their contribution to combat outcomes. Such an evaluation would permit comparisons between diverse systems and force components and evaluation of the combined value of groups of systems.

Simulation coula oe a powerful analytic tool for determining the contribution to combat outcomes of IEW/TA systems as it allows us to represent our understanding of the complex effects and relationships that characterize warfare and to observe the implications of our beliefs for different cases under varied assumptions. Unfortunately, intelligence and electronic warfare are not well represented in existing combat simulations. There are fundamental technical reasons why this is so, and technical challenges that must be addressed to support the analysis of the combat value of IEW/TA with simulation models. This document describes these challenges and considers how they might be met.

Not only will it be necessary to adequately represent the intelligence process in a simulation model, but a greater and more fundamental challenge is to take into account potentially large sensitivities of combat outcomes to multiple assumptions having unresolvable uncertainties.

Building combat simulations requires making assumptions with considerable uncertainty. For example, often the performance, effectiveness, and failure rate of systems in real combat can be estimated only from limited test or historical data. Initiating scenarios and force dispositions can only be guessed at. Various human factors that make real battles different from technical estimates must be allowed for in any simulation that is to be used to assess outcomes of actual combat. These must be arrived at through a combination of historical analysis and updating to allow for modern weaponry.

Uncertainties pose a problem for the use of simulation in assessing combat outcomes regardless of the nature of the simulation. Furthermore, the inclusion of IEW/TA causes a large increase in the amount of uncertainty above what must be addressed in simulations directed primarily toward lethal systems. Consequently, the use of simulation in evaluating the contribution of IEW/TA to combat outcomes requires innovative approaches.

There are two reasons why IEW/TA presents greater inherent problems with uncertainty: soft (human) factors and nonlinearity.

SOFT FACTORS

The product of intelligence is information. Intelligence influences the decisions of human actors. Simulating this effect requires modeling the decision process. For many purposes, all of the basic command, control, and communications network functions that support decisionmaking must be modeled as well. Models of human decisionmaking are generally inadequate and in any case are extremely difficult to validate. Decision models must in general represent a variety of "soft" or psychological factors that are difficult to tie to available data. These soft factors create serious problems for representation and for calibration of the model. Combat models that focus on lethal weaponry often neglect soft factors. This neglect is sometimes justified either because human factors are believed to be less critical than "hard" technical characteristics or because there are so many human actors involved that their actions can be represented statistically by aggregate probabilities,[1] depending upon the application. The effect of IEW/TA upon combat outcomes through *target acquisition* could perhaps be modeled by incremental changes in probabilities of kill. However, IEW/TA's contribution to *situation assessment* requires that the decision process of individual commanders be explicitly modeled. Because intelligence can affect critical decisions by individual decisionmakers, no appeal to statistics is possible, and the necessity of modeling the decision process cannot be avoided. Focusing only upon target acquisition would provide a more tractable problem but would systematically underestimate the value of IEW/TA. Furthermore, situation

[1]The use of aggregate parameters ultimately must be based upon an appeal to the "law of large numbers," where the summed effect of many human actions is modeled by the average over the ensemble of individual acts. This assumption will not be strictly valid in all cases but may serve as a useful approximation where no other approach is available.

assessment contributes to decisions and resulting situations that may increase or decrease the number and type of targets.

NONLINEARITIES

Intelligence is essentially catalytic in its effect, and like other sorts of catalytic phenomena IEW/TA has a highly nonlinear effect. Intelligence by itself has no combat effect, but it enhances the effectiveness of other force elements. In situations involving overwhelming force ratios, the combat value of intelligence could be negligible and have no effect on the outcome whatsoever.[2] When a single command decision means the difference between victory and defeat (for example deciding when to commit strategic reserves), however, the effect of one piece of critical intelligence is so nonlinear as to be essentially discontinuous. Strong nonlinearities in a model act as an "uncertainty amplifier." Small changes in inputs can result in large swings in outputs, so even small uncertainties in assumptions can result in large uncertainties in outcome.[3] The point is that no single case may be "representative." To evaluate the contribution of an IEW/TA system, its effect upon a wide range of plausible situations may need to be evaluated. How these various cases should be weighted in a summary evaluation will often depend upon what use the summary "measurement" is put to.

These two aspects of intelligence and electronic warfare have a series of practical consequences that have caused most combat models to avoid confronting the problems of modeling IEW/TA head on. Prominent among these consequences are:

- *Increasing the difficulty of sensitivity analysis.* Because the effects of intelligence can be highly nonlinear or discontinuous, doing a thorough sensitivity analysis is essential if the outputs of the model are to be used with confidence. Without adequate sensitivity analysis, study conclusions could be misleading. At the same time, modeling IEW/TA increases the amount of uncertainty that must be addressed. Sensitivity analysis may also become more difficult because analyzing the effects of single factor sensitivities no

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[2]If one is out of bullets, knowing where all the potential targets are to high accuracy is of little help.

[3]In the extreme case, nonlinearities can result in behavior that is formally chaotic (Gleick, 1987). However, even where chaos is not present, nonlinearities can strongly amplify uncertainties for some fractions of possible uses.

longer suffices. With strong nonlinearities, one must become concerned with multiplicative effects and cross factors.

- *Producing strong scenario-dependencies*. The operational value of IEW/TA will often be very scenario-dependent, and the details of the model needed to capture the interesting effects may also vary with the scenario. Consequently, a large range of cases may need to be run. Producing a single model that will be valid across all those cases may be quite difficult.
- *Making human judgment indispensable.* Human expertise is necessary in both construction of models and monitoring of case runs to insure that assumptions essential for the validity of a particular model are not violated in a scenario under consideration.
- *Creating large issue/answer complexity*. Because of the strong situation-dependence of outcomes, simple answers to questions of the operational value of IEW/TA may be few and far between. Instead, the results will need to be carefully bounded, and conditional factors will need to be kept clear. Simulations to support evaluations of IEW/TA need to be able to manage this complexity of results.

These problems imply that traditional methods of combat simulation may be inadequate to support the evaluation of IEW/TA systems. The OPVIEW project is pursuing a novel approach to providing computational support for studies evaluating IEW/TA.

This Note describes issues that must be addressed if the contribution of IEW/TA systems to combat outcomes is to be reliably determined through the use of simulation models, including the extreme sensitivity of combat outcomes to inherent uncertainties and the necessity of including the effects of human factors. Implications are drawn regarding desirable design features of computer simulations to support studies of IEW/TA's contribution to combat outcomes. A proposed modeling environment to support the construction of such simulations is also described.

II. UNCERTAINTY AND SENSITIVITY ANALYSIS

When uncertainties cannot be resolved through empirical research, they must be addressed in the modeling, either through the use of probabilistic models or through sensitivity analysis. In sensitivity analysis, possible errors in inputs to the model are estimated and corresponding error estimates on the outputs are calculated.[1] For arbitrary simulations the only method for doing this is to run excursions. For each case, multiple runs must be made to investigate how the outputs change as the inputs are varied inside their corresponding ranges of uncertainty. Unfortunately, the number of runs required to do this completely rises geometrically with the number of uncertain factors. Consequently, for most realistic simulation models, the number of runs per case required for a thorough sensitivity analysis is astronomical. In probabilistic modeling, values for uncertain quantities are selected at random and the model is run many times to characterize the range of plausible behaviors the model is capable of. Probabilistic modeling can be viewed as an automatic mechanism for performing sensitivity analysis and, when the number of uncertainties is large, will also require a prohibitive number of runs to be efficacious.

If simulation models are to make a contribution to evaluating IEW/TA, the number of excursions required to bound output uncertainties must be kept tractable. One approach is to use aggregated models so that the number of uncertain factors is kept small. Another possibility in addition to the bottom up approach of performing sensitivity analysis on cases is to utilize a top down, or question-driven, strategy of structuring a series of cases to maximize their contribution to useful answers in spite of the uncertainties. This is done by building and using simulation in order to best inform the answer to specific questions, rather than using general models whose design is data driven. In spite of the uncertainties, there is still much that we do know, and there are decisions that will be made regardless of how uncertain the world is. Any analysis of

[1]Uncertainties in parameters internal to a model are just as problematic as uncertainties in quantities that are formally "inputs." Thus an adequate sensitivity analysis must consider sensitivities to assumptions made in building the models as well as those made in choosing inputs for a particular run. All such quantities must be regarded as "inputs" to the modeling process, whether they are represented in the computer program as internal parameters or as external inputs.

value must look for some way to choose rationally among alternatives. For example, in choosing between alternative force structures, considering what results would suffice to indicate a choice can produce a list of cases that can then dictate which phenomena must be represented and constrain the process of sensitivity analysis.

Question driven strategies can be understood as an approach to sensitivity analysis based on a strategy of sampling the space of plausible cases. Where an exhaustive sensitivity analysis is impossible, it may still be possible to estimate plausible ranges on outcomes by sampling the list of cases that might be run in a thorough analysis. Formal derivation of a statistically correct sampling method will typically not be possible, so selection of the sample set will depend upon human judgment. This expert judgment will take the form of an analytic strategy in which critical cases are used to establish bounds on plausible outcomes given assumptions.[2] For example, an entire class of cases may be argued to be bounded by (be worse, better, greater, or less than on some scale) a critical case. In general this analytic strategy will not be initially specified in full detail. Instead, it may often emerge through a process of exploration using preliminary models. The emphasis will not be on finding the "best estimate" outcome, but on supporting a line of reasoning that holds in spite of existing uncertainties.

The process of question driven modeling implies a different style of model development than has often been the case. Whereas most modeling efforts begin with decisions about data representation and scope, modeling driven by the question must consider what hypothetical arguments might suffice to answer that question before deciding upon model characteristics. Details that turn out to be irrelevant to a particular question need not be included.

A complete sensitivity analysis may be impossible even with fairly aggregated models. Thus the process of determining the implications of what is known is a search through the universe of possible outcomes defined by what is not known. One approach to structuring this search is to use selective resolution: Preliminary modeling with highly aggregated models is followed by a thorough sensitivity analysis at that level to indicate where more detailed modeling could have the greatest influence on the final answer. This process can be done iteratively, with partial results guiding the process of model development, and with detail added only where it makes a difference. The result is a

[2]Care must be taken that the range of cases considered are not selected to produce the answer the analyst would like to see. Whatever criteria are used for case selection should be retained in the final documentation so that results can be objectively reviewed.

process where human judgment and machine computation both contribute to the evolving analysis.

For IEW/TA systems, a considerable portion of the value derived from situation assessment comes from exploiting special opportunities and avoiding being surprised. Consequently, the incremental value of an IEW/TA system will manifest itself primarily in special cases where such surprises or opportunities exist. To best estimate the added value of an IEW/TA system, such critical cases should be oversampled. A generic study might involve discovering "interesting" cases through an exploration of the space of plausible models and then studying the implications of different IEW/TA attributes on those cases. The process could well be iterative as new cases are identified in the course of analysis.

Wherever possible, OPVIEW will utilize highly aggregated parameterized models to support the evaluation process. Excursions to compensate for uncertainty regarding a parameter are easily generated as parameter values can be quickly changed. However, assumptions that cannot be adequately parameterized may also have associated uncertainties. These nonparametric uncertainties affect model structure and require the use of alternative models to investigate their implications. Consequently, exploratory modeling will in general require the use of models embodying alternative assumptions (e.g. commander decision style). These alternative models may differ from one another only in limited ways. Consequently, their use does not require generating many different models. Instead, investigation of the effects of minor changes can be facilitated by support for an understandable and modifiable model code.

One important source of uncertainty that is not parametric lies in the choice of combat scenario. (A given scenario may of course incorporate important parametric uncertainties such as mobilization duration.) To avoid the time-consuming task of scenario development for a large number of cases, the OPVIEW environment is intended to include a database of combat vignettes, which will provide the basis for exploring the range of combat outcomes through either their direct use or revision to suit a particular study.

In summary, modeling IEW/TA with support for aggressive sensitivity analysis may require the following:

- Aggregated modeling limits both the number of uncertainties and the time for individual runs.
- Question driven model development provides focused modeling limiting irrelevant factors.
- Analytic strategies provide a "top down" structuring of the list of cases that must be run.
- Selectively varying the resolution of the models allows for structuring the search of the universe of cases and optimizing the utiiization of analytic resources.
- Transparent modeling allows for rapid model revision, facilitating the use of multiple model variants for exploring the effects of nonparametric assumptions.

III. SIMULATION ENVIRONMENTS TO SUPPORT THE EVALUATION OF COMBAT OUTCOMES

Uncertainties present two fundamental technical challenges: how to provide the capability to run all the cases necessary to take unresolvable uncertainties into account, and how to make the resulting voluminous computer output produce a coherent answer.

KEY FEATURES OF NEEDED COMPUTER SOFTWARE

Large simulation modeling efforts have often encountered difficulty because of the complexity, unwieldiness, and lack of focus of models designed to serve a wide range of purposes. These problems have the potential of being especially troublesome for the simulation of IEW/TA effects on battle outcomes. Consequently, OPVIEW will need to employ a form of "exploratory" modeling in which the analyst starts from the policy questions and works in a top down fashion to call into play only those elements that prove relevant. The result of this method is that the model(s) used for each study will be somewhat different, built using the tools OPVIEW provides and relying upon the basic framework already built into OPVIEW's submodels.

The traditional approach to the development of computer models may be described as a two phase method. Phase one is the construction, verification, and validation of a model. Phase two is conducting a study by running cases on the model. Modeling IEW/TA in this fashion would result in answers without associated error estimates, and consequently would be ill advised. To produce a single valid model for all cases of interest would prove quite difficult, and adequate sensitivity analysis on such a model would effectively be impossible. Furthermore, the two phase approach tends to disenfranchise human experts who are not modelers, as the model that emerges from phase one is usually so complex as to impede man-machine teaming in understanding the dependencies of the results of the model runs.

We are now at a point in history where there are other possibilities besides this two-phase approach to modeling. One of the motivations for the two-phase approach has been the hope that valid models for complex systems could be created by modeling the

system in as much detail as possible. It is now recognized that such a hope is based upon false reductionism, a belief that more details will lead to a more veridical model.[1]

The two-phase approach to modeling reflects an earlier period in computer technology when computers were expensive and inaccessible, and there was little support for facile interaction between programs and users. Computer technology has now matured to a point where an interactive approach to modeling is feasible.

Interactive modeling means that model construction occurs iteratively, proceeding in parallel to the running of cases and guided by the progress of the analysis. It implies that the analysis will depend not on a single monolithic model, but rather upon an ensemble of models (some of which may be variants of a common root model). This style of analysis requires not only a computer model but an entire environment to support the iterative and adaptive modeling process. With such an environment it will be possible to conduct analyses in a much more flexible fashion than has been possible in the past.

This flexibility will require computer tools that support facile model revision. Examples of candidate tools are the RAND-ABEL® language (Shapiro et al., 1985, 1988), which greatly facilitates ease of revision, and libraries of potentially useful model components. Parameterized baseline models can support exploration through parameter setting and model revision. The baseline models could also allow a limited range of variable resolution. Preliminary modeling could then be done by turning off major sections of the models and setting parameters in the resulting highly aggregated version. Such model variants could be produced through simple revisions to RAND-ABEL decision tables.

A potential problem created by frequent model revision is one of configuration management. We hope eventually to introduce tools into the OPVIEW environment to mitigate this problem.

The modeling of IEW/TA's contribution to combat outcomes could be greatly facilitated by a computer environment to support modeling through:

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[1]Unless all of the parameters of a detailed model can be determined from more accurate data than their corresponding aggregate parameters, the addition of detail is likely to *reduce* the accuracy of the resulting model. The sum of many measurements will generally have more error than a single measurement of the sum. Where there is uncertainty, a detailed model will contain many more uncertain assumptions than will an aggregate one. Clearly, what is desired is the correct amount of detail for the model's purpose. As this purpose varies, so must the level of detail.

- A programming language and software tools supporting interactive and adaptive modeling.
- Aggregated and parameterized baseline models that may be modified in the context of specific studies.
- Transparent model computer code.
- Standard database and graphical display tools.
- Configuration management tools.

These facilities will allow a large number of cases to be run in support of any specific analysis of combat value. Generating these runs may be regarded as the first half of an analysis of combat value. The second half is to generate a coherent picture of all the relevant tradeoffs, to boil down the complexities of the sensitivity analysis to a representation that will provide useful input to decisionmaking.

The results of cases that are run provide a database of assumption-outcome pairs that then present a problem in data modeling or data synopsis. From the complexities of multiple cases, useful conclusions are sought. The task of finding coherent meaning in complexity falls primarily on the insight skilled human analysts provide. In this task the analyst can be assisted by computer software that facilitates manipulation and display of the data.

The process of exploratory simulation, which could be used to produce an analysis of the sensitivity of combat outcomes to IEW/TA capabilities in the context of other assumptions, will result in voluminous amounts of complex data. This complexity must be summarized in a way that is useful to potential consumers of the analysis, requiring the active involvement of human analysts but greatly facilitated by appropriate computer support. In effect, the simulation cases produce a database of outputs, so powerful tools are also needed to support the examination of this database. Taken together, the entire system can be described as a computer tool for visualizing decision spaces with uncertainty.

SIMULATION ENVIRONMENT FEATURES

The features described above constitute a specification for a general computer modeling environment. Such an environment would support a highly interactive style of use where a smart user (not necessarily a computer expert) can explore the implications of various situations, intel system mixes, employment strategies, and so forth.

An environment developed by the OPVIEW project (referred to as the OPVIEW environment) should include a set of highly aggregated, parameterized baseline models capable of being modified during the course of the analysis. These models should be constructed in a language and style that allow people who are smart about intel but not necessarily geniuses with computers to examine, critique, and modify them. The models produced would ideally support selectively variable resolution where preliminary analysis uses highly aggregated models. Based on this preliminary analysis a limited number of higher resolution cases may be specified, where both the case specification and the parameters that are disaggregated are suggested to make a critical difference to the final answer in the study of interest. The higher resolution model used could either be a revision of the baseline models or another high resolution model the Army favors. When used to suggest cases for a higher resolution model, the OPVIEW environment could be seen as a sensitivity analysis tool used to augment the utility of the larger model.

The modeling process OPVIEW is pursuing depends critically upon computational facilities that have only recently become available. What needs to be constructed is not so much a single combat model as a modeling environment, containing models, databases, graphical interfaces, and other tools to help manage the complexity of the problem being addressed.

In constructing this environment OPVIEW is utilizing the RAND Analytic Modeling Platform (RAMP), a general purpose simulation environment generated as part of the RAND Strategy Assessment System (RSAS) (Davis et al., 1986; Davis and Winnefeld, 1983). The RAMP supports rule-based modeling using the RAND ABEL language, combat adjudication using the SLAND methodology (Allen and Wilson, 1987, 1988) and numerous graphical displays, editing tools, and other features (see Fig. 1).

OPVIEW BASELINE MODELS

Inside the RAMP, OPVIEW is constructing a suite of models (see Fig. 2), including a combat adjudication model, Red and Blue versions of sensor models, intelligence models, and decision models. These are not intended to be final products that will be sufficient for any analysis undertaken using the OPVIEW environment. They should be regarded as base-line models that will be revised in the process of most analyses. Their function is to provide a library of model components together with a structure to ease the process of model revision.

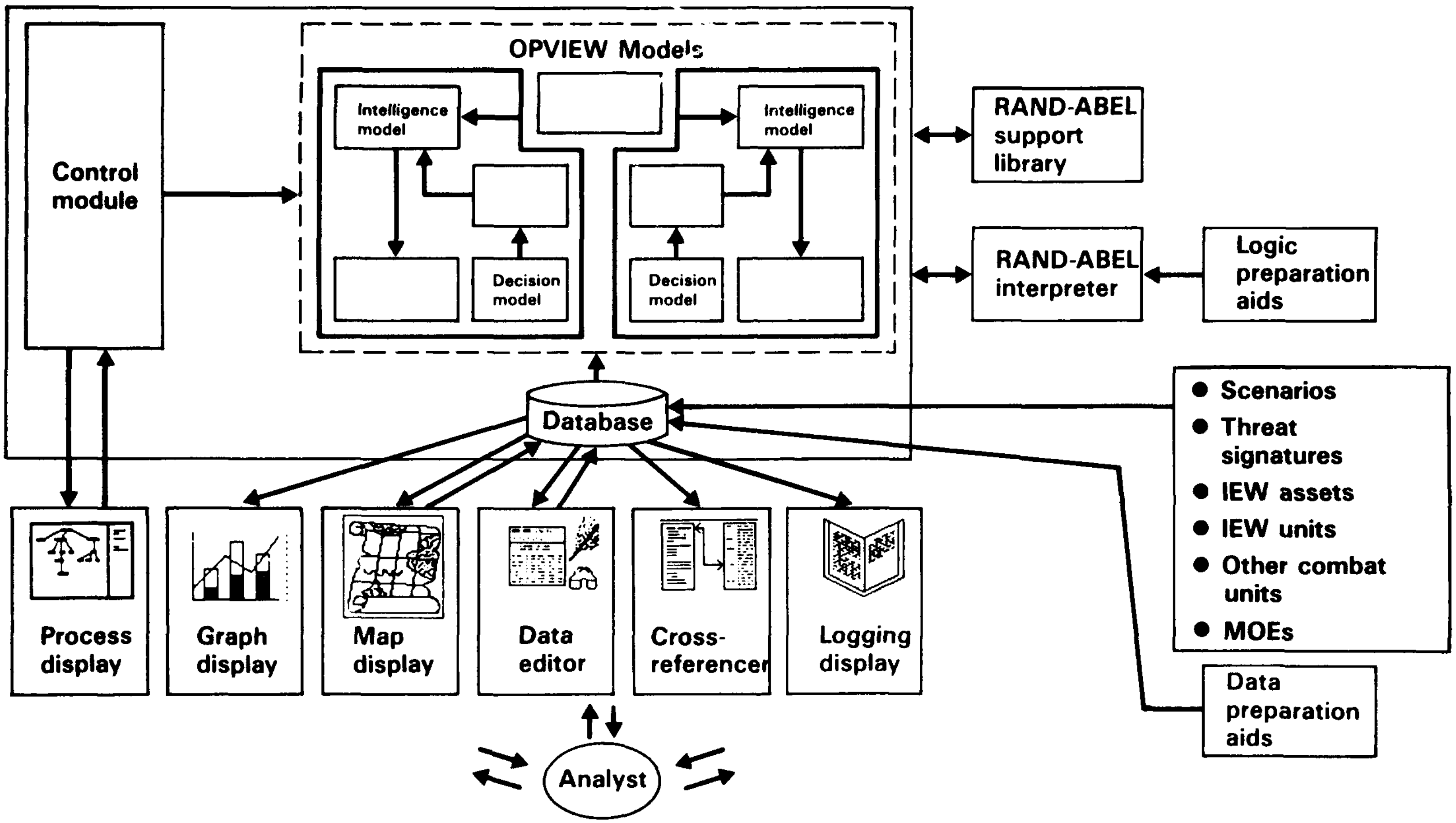

Fig. 1—RAMP modeling environment

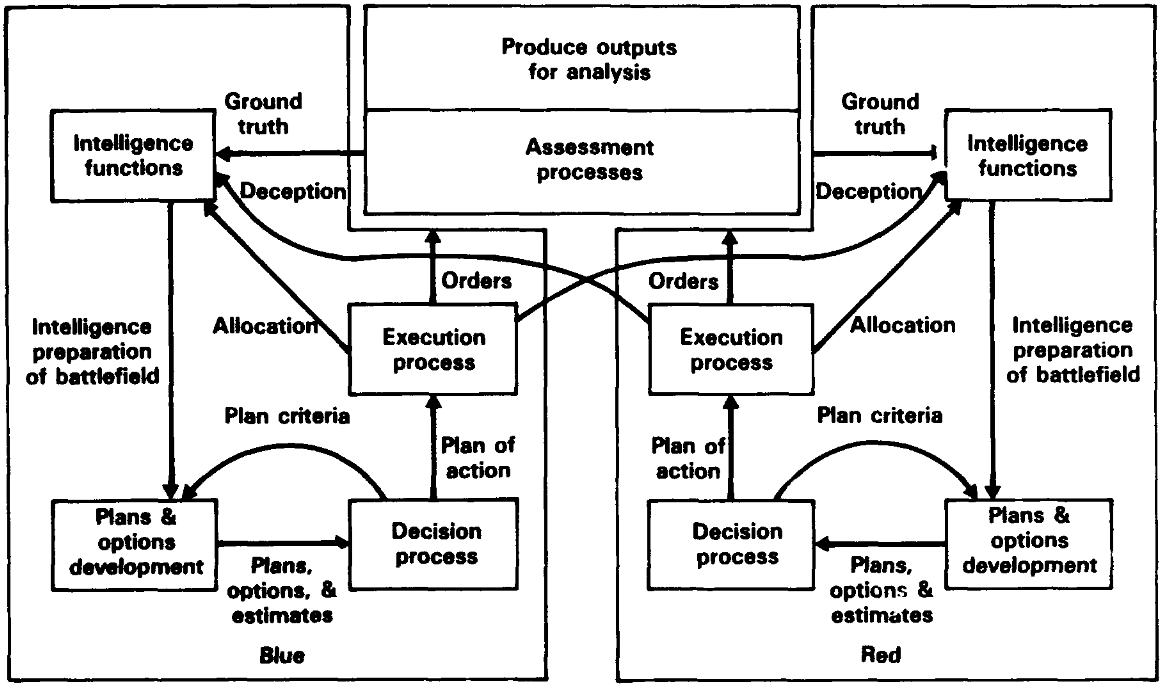

Fig. 2—Operational value of intelligence model data

While the diagram in Fig. 2 is Red-Blue symmetric, what goes in the boxes will be asymmetric, with Red systems represented in the Red Intelligence model, Red decision styles in the Red Decision models, and Red-Blue asymmetric forces in the combat adjudication model.

The combat adjudication model contains a representation of the battle and computes combat outcomes. In OPVIEW it is based upon the design of the SLAND model (Allen and Wilson, 1987, 1988) developed for the RSAS. It is based upon a Line of Communication (LOC) representation and was designed to allow for developing new theater models in short periods of time. This will allow the OPVIEW environment to be used in studies for a variety of theaters and levels of combat.

The representation of ground truth produced by the combat adjudication model is input to the two Intelligence models, which produce respectively a Blue or a Red view of the battlefield, depending upon what systems are up and what their capabilities are. The outputs of the Intelligence model are based loosely upon the Intelligence Preparation of the Battlefield (IPB) and are aggregated in terms of geographic areas and types of target.

The output of the Intelligence model report is input to a decision and execution process that produces orders to forces, tasking to intelligence assets, and possible deceptions and countermeasures that affect the intel process of the opponent. The decision models are not intended to be artificially intelligent or to serve as simulations of the decisionmaking process of real decisionmakers. The critical decisions to be made are prescribed by the combat vignette and will generally be described by a rather sparse (situation-dependent) decision tree. The computer code describing these decisions will need to be provided for each vignette. However, this case-specific code can be kept terse by use of utilities for situation assessment, order generation, and battle management. Such utilities will be provided with the OPVIEW environment.

While most combat models tend to become highly detailed, the OPVIEW system of models is designed to be quite broad but correspondingly shallow. The intent is to represent all factors that enter into determining combat value, even those that are not well understood and can be represented only parametrically. Where high quality numbers are available, they should be used. Where they are not, a parametric approach will be taken, with sensitivity analysis determining what effect these "guesses" have upon the final answers.

USING OPVIEW TO EVALUATE IEW/TA'S CONTRIBUTION TO COMBAT OUTCOMES

The OPVIEW environment will be used in studies to support running a large number of cases using various assumptions. The outputs of all those cases will be used to produce coherent answers to the questions the studies address.

On any run of the model, four kinds of numbers may be regarded as candidate measures of IEW/TA value (see Fig. 3). First there are technical parameters, such as sensor resolution or range, that are inputs to our system. At the other extreme are the actual combat outcomes such as attrition or forward line of own troops (FLOT) movement. Both sensor resolution and FLOT movement may for some cases represent a measure of Intelligence quality; the first reflects capability and the second outcome. Intermediate products of the simulation may also serve as candidate measures. The outputs of the intel model provide measures of how complete and accurate Blue's (or

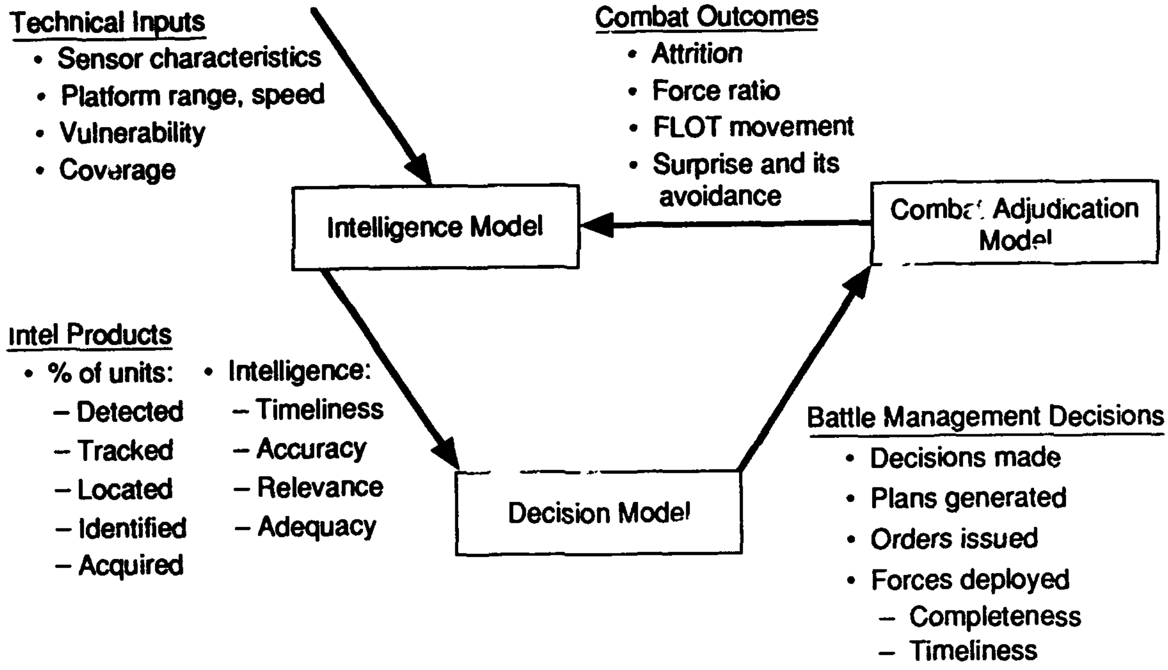

Fig. 3—Ways OPVIEW can be used to measure IEW/TA's contributions

Red's) view was (or for countermeasures how deceived Red was). Outputs of the Decision model(s) can be used as measurements of how good the decisions were with alternative IEW/TA systems.

While combat outcomes are the ultimate measure of IEW/TA quality, the volatility of combat outcomes may often be such that they alone may be inadequate to reveal patterns among a feasible number of cases. Understanding how IEW/TA qualities lead to combat outcomes is essential to being able to reach reliable conclusions about the relation of combat outcomes to IEW/TA characteristics.

The various technical inputs and intermediate results constitute a large pool of potential measures of IEW/TA quality. Across a large number of runs, a sizable database of such results described in terms of all these potential measures will be generated. The central analytic task beyond selecting cases will be to examine that database to discover patterns of correlation from which causality can be inferred. The database will be used to determine which technical or intermediate measures are most predictive of combat outcomes.

In simple cases the presence of a particular system may produce fixed changes in combat outcome. However, results are generally more complicated than that, and the detailed results of a study may require a decomposition into classes of cases and for each class a portrayal of the relationship between the key factors and combat outcomes.[2] The observed relationships may be conveyed in a variety of ways depending upon its complexity, including the use of graphs, tables, or even a summary spreadsheet model to capture the pattern of results seen in the multiple-case runs. These various representations constitute simplified models synopsizing the general behavior of more complex models inferred from numerous cases.[3]

To understand the contribution IEW/TA makes, we must also determine when that effect will obtain and why it occurs. Understanding not only the "what" but the "when" and the "why" is essential if we are to understand the outcomes of studies and convince others of their veracity. The OPVIEW simulation environment should be useful for asking not only "What is the value of an IEW/TA system?" but also "When (under what conditions) will it have that value?" and "Why does it have value?" This tool could prove useful for examining alternative mixes of systems, understanding synergistic effects (e.g. cueing), and seeing implications for employment issues. Consequently, although OPVIEW has focused on measuring the combat value of IEW/TA, the product should provide decision support for a broad range of issues as well as measurements.

Furthermore, the methodology OPVIEW is pursuing does not lead to a "magic yardstick" providing hard and fast measure of combat value.[4] Instead, it should endeavor to produce a decision aid that will illuminate tradeoffs and essential uncertainties. Such a tool would be of value to decisionmakers who must consider costs and risks as well as benefits.

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[2]Depending upon the study, combat outcomes may be aggregated in a variety of ways including average or worst-case outcome.

[3]Such simplified data models have been referred to as repro models (Goeller et al., 1985).

[4]Because of the complexity of the phenomena involved, such simple measures (e.g. JSTARS = 3.4 armored divisions) will not be possible except when caveated by attendant assumptions.

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